7

RIVER MURRAY FLOOD FLOW PATTERNS AND GEOMORPHIC TRACTS

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ABSTRACT: During severe floods, as in 1974 and 1975, large volumes of water leave the River Murray on the Victorian and New South Wales sides. A flood flow of 200,000 Ml/d* in the river at Tocumwal can reduce to 30,000 Ml/d in the river at Barmah, and 200,000 Ml/d in the lower Goulburn can reduce to 30,000 Ml/d at Swan Hill. Variations in flood plain dimensions reflect the magnitudes of overflows from various lengths of the river. The modern course of the river traverses parts of the ancestral flood plains of its tributaries, and part of the Riverine Plain. By reference to these older features, five river tracts can be distinguished in sequence from the highlands above Corowa to the Mallee below the Murrumbidgee junction.

* Ml = 1,000,000 litres = approx. 0.8 ac. ft
Gl = 1,000 Ml
Ml/d = approx. 0.4 cusecs

FLOODS AND FLOOD PLAINS

River Murray levels have been recorded at Echuca Wharf since September 1865. From May 1906 permanent gauges were established along the river, and flood records from them show that the river was in flood throughout its length during 1870, 1916-17, 1956 and 1973-75, and that in other years localised flooding occurred depending on which tributaries were in flood.

In the past, flood discharge records and recorded flow patterns, together with analysis of characteristics of the river and its flood plain have been used as the basic information for the design of levees at the most suitable locations to minimize flood damage. Early attempts to levee the River Murray were approached with caution since it was well recognised that both the flood hydrology and the geomorphology of the flood plain were complex. In 1921 an interstate committee (New South Wales & Victoria) recommended criteria for the consideration of further flood protection and reclamation works. These criteria were developed taking into consideration that in the event of a flood of the magnitude of 1917, the volumes of active flood pondage were 2,000 Gl in New South Wales and 700 Gl in Victoria; the average depth in Victoria was about 1 m whilst in New South Wales it was only 0.5 m. In considering future strategies it is of interest to note that the analysts of the day (1921) computed that the effect of a complete leveeing of the main Murray channel would be to raise the flood level at Swan Hill by some 7.5 m. The significance of this extreme approach was not lost; the cost of these works was seen as 'absolutely prohibitive whilst the resulting menace to the land at present free from submergence would be very serious and absolutely unjustified'.

Current analysis aims at establishing the reasons for flood flow patterns so that flood plain management guidelines can be formulated for planning in the future. This is essential because of the flat gradients traversed by the river. The gradient of the plain is 1:5,000 so that usually insignificant land forms such as natural river levees, up to 1 m high, have a significant effect on flood flow paths and cause extensive sheets of water to become ponded behind them.

Broadly, flow patterns show that the flood waters are retained within the flood plain above Corowa and below Boundary Bend, but in between the water overflows onto the Riverine Plain. An extreme instance is the situation that has arisen on several occasions at Barmah where the effect of flood inflows from the Goulburn River has been to reverse the hydraulic gradient to the extent that flow at Barmah actually reverses. This is illustrated by the peak discharge chart of the May 1974 flood (Fig. 1). Peak flow passing Tocumwal was

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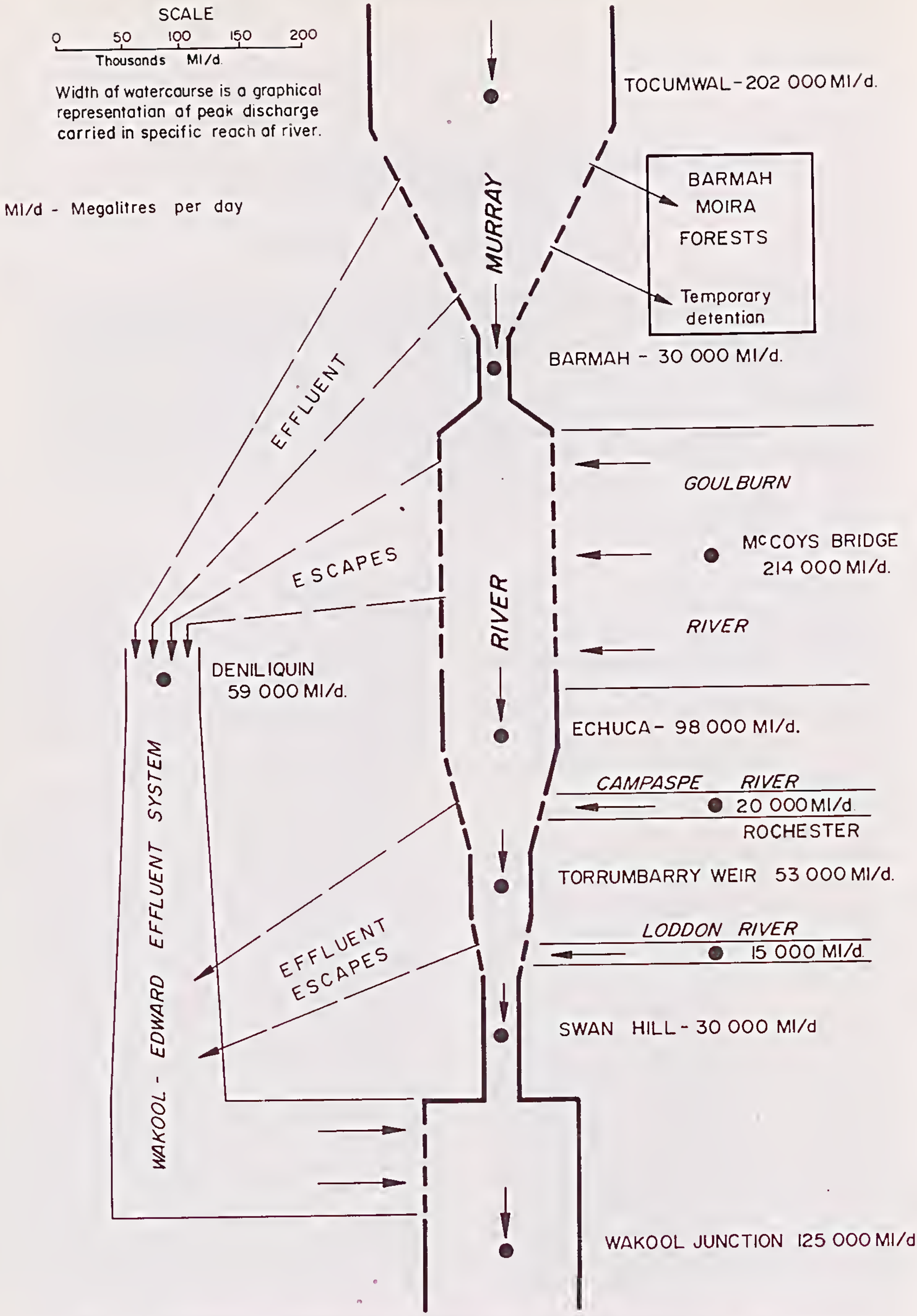

FIG. 1 — River Murray, tributaries and effluents. Peak discharges during the May 1974 Flood.

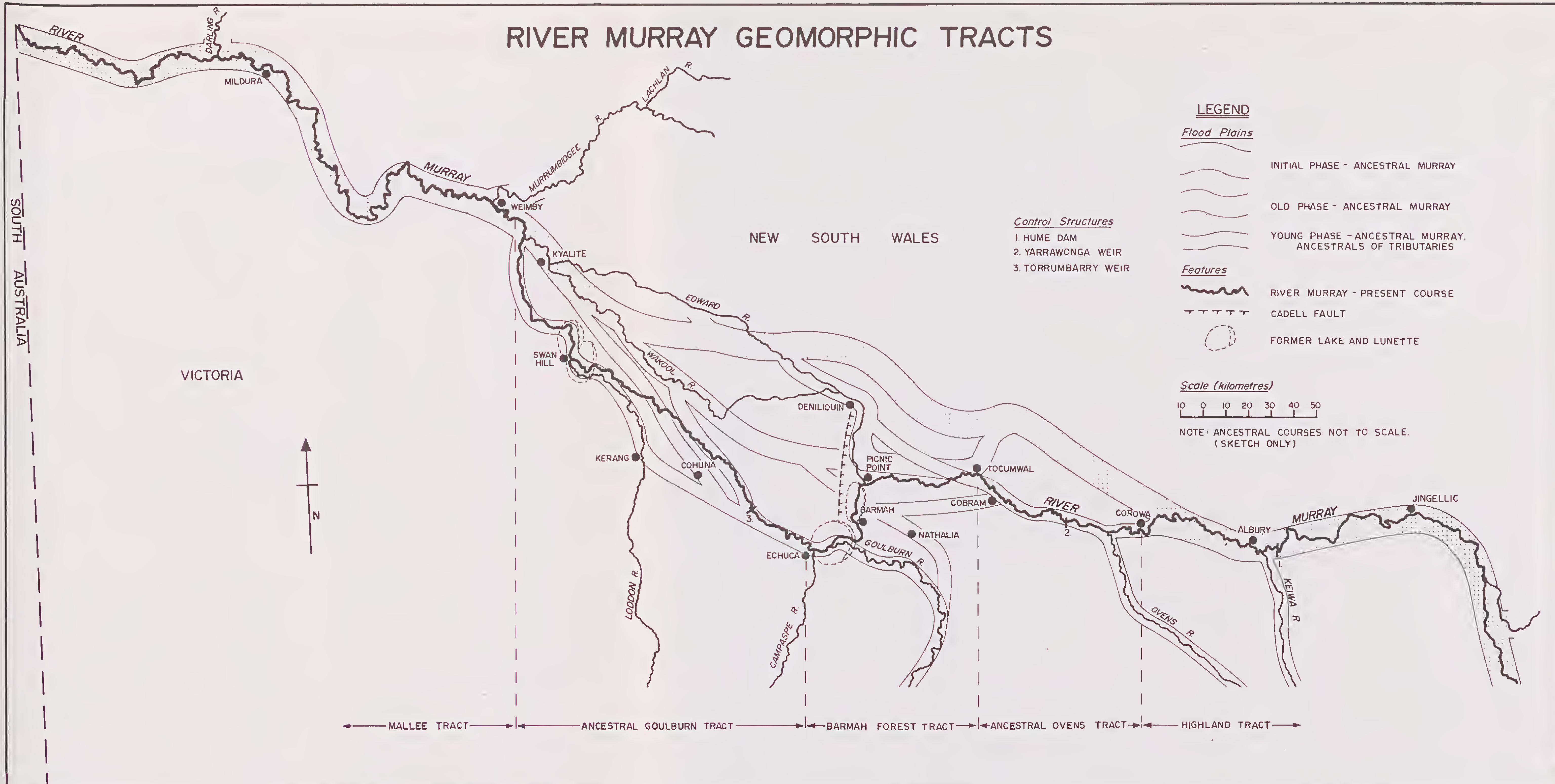

FIG. 2 — River Murray tracts showing ancestral courses of the river system.

202,000 Ml/d but downstream at Barmah was only 30,000 Ml/d because the water had overflowed either into the Barmah Forest or the Edward River. The reason for this flow behaviour becomes evident when the relationship between the past and present drainage systems are recognized.

The former courses of the Murray's immediate precursors, the ancestrals, were first described and mapped by Pels (1964), and since then geologists have mapped the ancestors of the tributaries. Pels showed that 'following the final depositional phase of prior streams (Butler 1950), a phase of large-scale incision occurred and resulted in a system of deep wide channels across the plain'. Also he demonstrated that there were three distinct phases before the present Murray established its course. Although the sequence of ancestral Murray flood plains can be clearly defined, they will be labelled as either old or young when describing their relationship with the present flood flow paths.

The purpose of this paper is to demonstrate the controlling effect of the ancestral tracts on flood discharge behaviour, thus providing example of the control exerted between Quaternary geological evolution and the modern hydrologic regime. The valuable contributions by Pels and Bowler in describing these ancient systems allows an understanding of past hydrologic history which bears directly on modern river management. Practical use can be made of their work in hydrology flood studies for levee design and for predicting trouble spots along the river, as well as in adding to the basic data needed for the future management of the flood plain.

By super-imposing the flood patterns on their geomorphic maps it is evident that depending on where the Murray is today with respect to the ancestral flood plain system it can be divided into ancestral tracts, as these control the flood pattern.

The term flood plain will be used in the descriptions of the various ancestral systems, and in this paper the river is said to possess a flood plain when it is flowing in an alluvial belt of country lying slightly below the surrounding plain. This best represents deposits of the present or earlier phases of river development. In this sense the flood plains represent the upper surface of bodies of alluvium inset into the plain. When no such inset relationship occurs, as when the river is not associated with any particular ancestral course but may be cutting across earlier channel traces, the river is said to lack any associated flood plain.

ANCESTRAL TRACTS

Detailed geomorphic mapping from aerial photographs, soil maps, contour plans, and field studies has enabled us to trace the system of river channel evolution (Fig. 2). Although this agrees well with maps produced by Pels (1966) and Bowler-Harford (1966) it differs in one respect in that we include one channel system in the history of the Murray evolution that predates that which Pels referred to as ancestral river Phase 1, the Green Gully Phase. The Green Gully Phase followed this older system and broke out of it at Tocumwal. However, Pels (1966) described the lower end of this older system and named it the Tulla River Branch. He stated that the Tulla Branch shows that 'Coonambidgal I sediments were re-excavated during this phase (Coonambidgal II). Residuals now remain as terrace remnants along the sectors of the river where the two phases are superimposed' The Goulburn was a tributary of Green Gully and it also followed an earlier phase along the Tallygaroopna system, with similar older terrace remnants. Therefore our suggestion questions the validity of Bowler's (1966) naming of the Tallygaroopna system as a prior stream. This involves instead a large Murray system, which leaves the Murray at Corowa and flows west passing north of Deniliquin. Its surface blends in with the general level of the plain approximately 10 m above the Murray flood plain, and it is flanked by sand dunes along its length. Furthermore, the 30 m thickness of sand and gravel infilling the ancestral valley is abruptly terminated at Corowa, and the flood plain is eroded in Riverine clays downstream from that point. This can be explained if the infilled valley followed the suggested course north of Corowa.

In the terminology of Pels (1964) and Butler (1950) this early system may be termed a prior stream. In the sense in which we are using the term it constitutes one of the early ancestral courses of the present day Murray. Also the early ancestral courses of the Goulburn are revealed when the aeolian material is artificially removed from the Tallygaroopna system. A false impression is given by the wind blown sand, that the Tallygaroopna is of the prior stream raised type of topography, but, as shown in Fig. 3, it is revealed as an ancestral type incised below the plain.

Pels had the ancestral systems dated and named them Coonambidgal I, age exceeding 28,600 years; Coonambidgal II, age 26,200 to 13,400 and Coonambidgal III, age 9,800 years. The present course is 9,000 years old (Bowler, pers. com.). Bowler's (1966) date of the Tallygaroopna N306-20,300, coincides with the Coonambidgal II age. Subsequent bores have proven this stratigraphically, and in addition that gravel beds below belong to Coon-

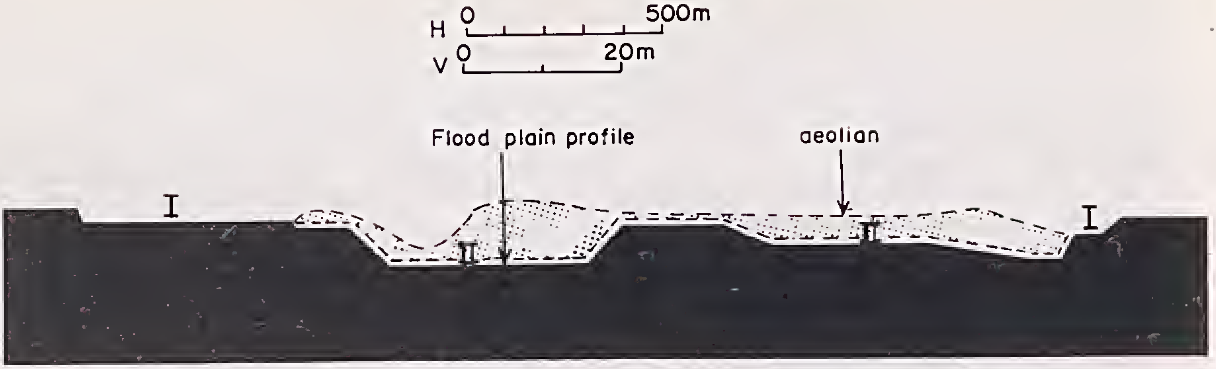

FIG. 3 — Tallygaroopna system — ancestral Goulburn. Aeolian sand covers Coonambidgal I and II flood plains. (Parish Tallygaroopna, Lot 30.)

ambidgal I, as previously argued by Pels. The complication to the Green Gully system is due to its disruption by the Cadell Fault during the early stages of Coonambidgal II development. It continued as the diverted Murray named Gulpa Creek (Pels 1964) and the diverted Goulburn named Kotupna (Bowler 1966).

The older ancestrals of the Murray were diverted north by the Cadell Fault, past Deniliquin into the Wakool System, which is the downstream end of the disrupted Green Gully System. Later the younger ancestrals eroded a gap at Corowa into the old and younger ancestral Ovens flood plains. The old Ovens continued west past Cobram to join the Tallygaroopna-Goulburn near Barmah. The younger Ovens-Murray continued to Tocumwal, formed the Bullatale and joined the old Murray at Deniliquin. The Tallygaroopna was defeated by the fault but survived as the Kotupna system (late Coonambidgal II) which eroded a gap in the Barma sand hills, crossed the Kanyapella lake floor and flowed west, past Echuca. It branched at Cohuna: one course entered the Wakool-old Murray system, and the other course continued past Kerang, crossed a lake floor at Swan Hill and returned to the old Murray system at the Wakool Junction.

RIVER TRACTS

The dimensions and features of the River Murray flood plain change rapidly after the river leaves its oldest ancestral flood plain at Corowa (Fig. 4). It occupies, in turn, the ancestral Ovens flood plain, the Moira-Kanyapella lake system and the ancestral Goulburn flood plain before returning to its oldest ancestor at the Wakool River junction, in the Mallee. In total there are five distinct tracts along the New South Wales-Victorian border. These have been named to correspond with the geomorphic history of each tract (Fig. 2) as the:

Highland Murray Tract, from the headwaters to Corowa.
Ancestral Ovens Tract, Corowa to Tocumwal.
Barmah Forest Tract, Tocumwal to the Goulburn River.
Ancestral Goulburn Tract, Goulburn River to the Wakool River.
Mallee Tract, downstream from Wakool River.

The tracts are highlighted by the graphical representations of the flood peak discharges, May 1974 (Fig. 1) and October-December 1975 (Fig. 5). The 1974 record shows discharges between Tocumwal and Wakool Junction and the 1975 record from Jingellic (New South Wales) to Blanchetown (South Australia).

HIGHLAND TRACT

The headwaters of the River Murray are in the Great Dividing Range where the river and tributaries flow in steep narrow valleys. Floods in these reaches of the Murray rise rapidly to peaks and subside almost as quickly, and are confined to the flood plain. An example of the rapid rise and fall was the flash flood in March 1964, on Copabella Creek, a tributary at Jingellic. A peak flow of 60,000 Ml/d from a catchment area of only 250 km^2 occurred about two hours after an extremely heavy thunderstorm concentrated over a small area. This peak was attenuated (flattened out) as it passed downstream, to 44,000 Ml/d in the Copabella at Jingellic and 34,000 Ml/d in the Murray two km further downstream. Even without the effect of Hume Dam, a localised flood of this nature would have had no great effect below Albury. The significance of flash flooding is evident when compared with the 1975 Murray flood peak discharge at Jingellic, which was 126,000 Ml/d from a catchment area of 6,527 km^2 (Table 1). The

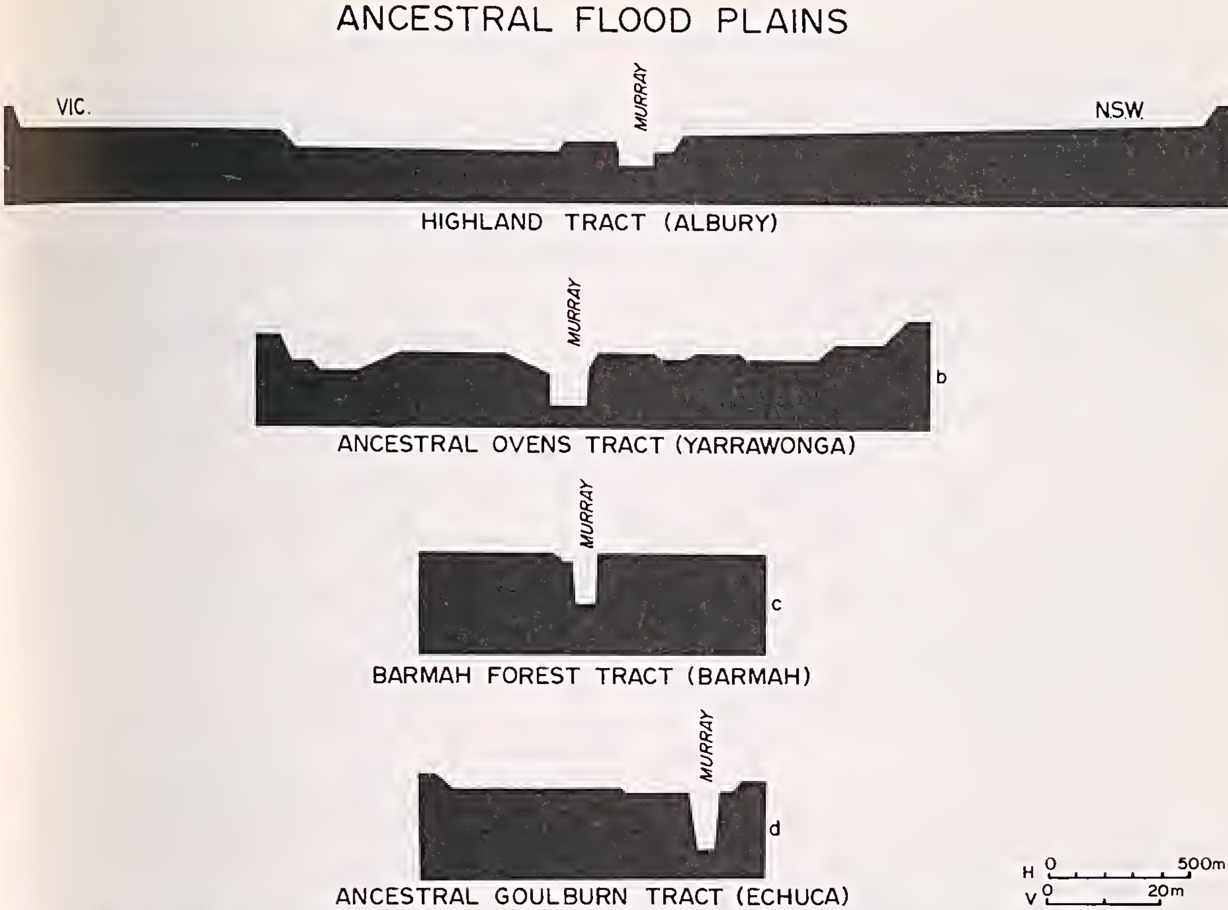

FIG. 4 — Flood plain sections of the tracts. Comparison between the dimensions shows the flood retention capabilities of each.
Note. — The River Murray flood plain dimensions decrease downstream from Albury. Beyond Wakool dimensions increase.

discharge had increased to 163,000 Ml/d at Albury.

The Highland tract is continuous from the Murray headwaters to the township of Corowa, a length of 450 km. The tract retains the flood plain remnants from all of its ancestors (Fig. 4a), as far as Corowa where the younger ancestral flood plains, 10 m below, leave the older.

Tributary valleys contain the same components as the main stream. These were briefly described by Rowe (1967, 1972) as 'mature valleys with broad alluvial flats and raised terraces'. The flood plain extends the full width across the valley, often abutting against bedrock. River channel meanders are angular, separating relatively straight reaches of river. The river's channel is shallow and wide, often more than 150 m. Banks consist of sand and gravel whilst cobbles are common on the bed. A typical section at Jingellic, 100 km upstream from Albury, shows these features. Ancestral river flood plains and terraces have been formed over the deep lead gravels, which infill the valley to 70 m. Here the flood plain extends across the entire river valley with modern point-bars inset within adjacent older alluvial sediments.

At the downstream end of the tract, near Corowa, the flood plain widens and is marked by numerous abandoned river channels and meander scrolls. The river bed and banks are in sandy materials and these deposits extend to 30 m below the river bed.

ANCESTRAL OVENS TRACT

The River Murray leaves the foothills and bedrock outcrops at Corowa and enters the Riverine Plain. At Corowa the flood plain narrows as the river leaves its older ancestral flood plain and erodes through a narrow gap to connect with the

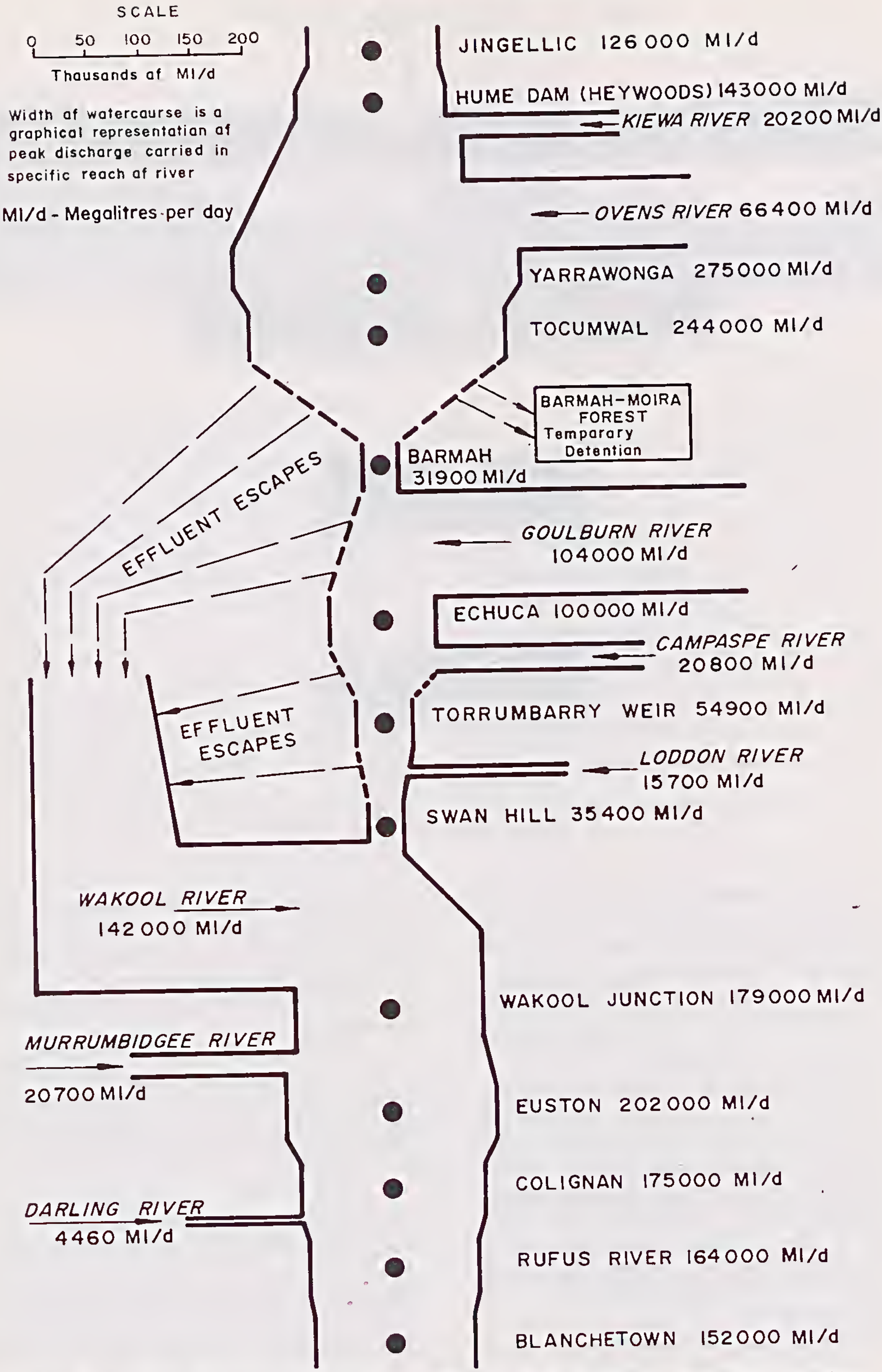

FIG. 5 — River Murray, tributaries and effluents. Peak discharges during the October-December 1975 Flood.

TABLE 1
RANGE OF DISCHARGES—VARIOUS STATIONS.

Stream	Station	Catchment Area km^2	Maximum Annual Discharge		Minimum Annual Discharge		Mean Annual Discharge over Period of Record		
			Year	Discharge Gl	Year	Discharge Gl	Period	Discharge Gl	Depth mm
Murray	Jingellic	6 527	1917-18	6140	1902-03	677	1890-1970	2374	364
Mitta	Tallandoon	4 716	1917-18	4268	1902-03	250	1886-1970	1415	300
Kiewa	Kiewa	1 145	1917-18	2077	1914-15	166	1886-1970	634	554
Ovens	Wangaratta	5 411	1917-18	4924	1902-03	174	1887-1940	1444	267
Goulburn	Murchison	10 772	1917-18	7390	1940-41	146	1882-1970	2145	199
Campaspe	Elmore	3 398	1956-57	823	1944-45	0.8	1886-1964	237	70
Loddon	Laanecoorie	4 178	1893-94	743	1944-45	9.3	1891-1966	231	55
Condamine —Maranoa		87 000	1950	6660	1923	8.1		1050	12
Macintyre Basin		37 200	1950	4320	1940	100		875	24

Note: Figures are actual flows. No account is taken of diversions or storage construction during period of record.

ancestral Ovens flood plains. The sediments and terraces of the Ovens River were described by Newell (1970). The river remains in the ancestral Ovens tract, as far as Cobram, where it leaves the older Ovens to follow its younger ancestral flood plain to Tocumwal.

The whole discharge from a Murray flood passes along the present river course to Tocumwal. Flood peaks at Yarrawonga are influenced by the Ovens and Murray peaks, which may or may not be coincident. Major flood peaks occurring during prolonged periods of high flow are not significantly attenuated along this reach of the river: for example peaks in the 1975 flood (Fig. 5) were:

Outflow from Hume Dam	143,000 Ml/d
Kiewa River	20,200 Ml/d
Ovens River	66,400 Ml/d
Total	229,699 Ml/d

Peak outflow from Yarrawonga Weir was 275,000 Ml/d which approximates the sum of the inflows when unmeasured inflows from minor upstream tributaries are included.

Significant pondage of floodwater occurs on the flood plain between Hume and Yarrawonga, and in smaller floods, and outside periods of prolonged high flows some attenuation of peaks is evident. A flood peak will usually take two to three days to pass from Hume to Yarrawonga and a further day to reach Tocumwal (Table 2).

During the disastrous floods of 1917 substantial areas in Victoria between Cobram and Barmah were flooded because of flood breakaways from the river. Following these floods a comprehensive system of levees was constructed along the Victorian side. The October 1975 flood, which was of similar magnitude to the 1917 event, breached these levees in a number of locations below Cobram, including sections at their connections with sand dunes. The breakaway water flowed westerly along a former major river course (old Ovens) overland towards Barmah and in the process caused substantial flooding on its former flood plain.

The ancestral Ovens tract, between Corowa and Tocumwal, a distance of 90 km, contains the older ancestral flood plains of the Ovens River and the younger ancestral flood plains of the River Murray (Fig. 4b). The older ancestral section in this tract can accommodate the flood flows; however, the succeeding ancestral sections become progressively smaller, and at Cobram leave the older flood plains. Flood overflows occur along the older flood plain to the west as flows become restricted by the smaller, younger flood plain immediately to the north. The flood plain below Corowa is 3.2 km wide and consists of terraces etched in the Riverine Plain clay

TABLE 2
PEAK DISCHARGES — 1975 FLOODS.

Station	Peak Discharge Ml/d	Date
Jingellic	125 900	26/10
Hume (Heywoods)	143 000	27/10
Yarrawonga	275 000	29/10
Tocumwal	244 400	30/10
Barmah	31 900	2/11
Echuca	100 300	4/11
Torrumbarry	54 900	3/11
Swan Hill	35 400	15/11
Wakool Junction	179 000	23/11
Euston	202 300	25/11
Colignan	175 000	30/11
D/S Rufus River	163 800	14/12
Blanchetown (Lock 1)	151 700 (Est.)	17/12
Kiewa River	20 200	26/10
Ovens at Wangaratta	66 400	26/10
Goulburn at McCoys	103 900	29/10
Campaspe at Rochester	20 800	26/10
Loddon at Highway Bridge	15 700	1/11
Murrumbidgee at Balranald	20 700	31/10
Darling at Burtundy	4 460	14/12
Wakool at Kyalite	141 800	18/11

sediments. The modern river meanders sinuously over the flood plain, sometimes following but often out of phase with inherited ancestral meanders. Moreover, compared with the river in the upstream tract, the modern channel is relatively deep and narrow.

BARMAH FOREST TRACT

The dominating flow path feature of the Barmah Forest Tract is the Edward-Wakool effluent system, which receives the greater part of the river flow during major floods. For example during three months October-December 1975 some 55% of the total volumes passing Tocumwal overflowed into the ancestral river courses in New South Wales, to join the Edward River at Deniliquin.

In this tract, between Tocumwal and the Goulburn River junction, flows frequently exceed the river channel capacity of about 11,000 Ml/d and spread out to cover the forest floor. Flood overflows into the Edward River may be caused either by direct flood flows or by the effects from floods in the Goulburn and Campaspe systems forcing the Murray waters to back up, and in extreme instances around Barmah, to reverse the normal direction of flow.

The ease with which flooding can occur or change direction is due to the absence of flood plains in this tract (Fig. 4c). The river is limited in capacity, with a maximum channel capacity in relevant sections of around 11,000 Ml/d. This results in overflow into the adjacent lake and swamp formations. Even during major Murray floods, the peak flow through a restricted section known as the Barmah Choke does not exceed 30,000-35,000 Ml/d, although flows past Tocumwal may exceed 200,000 Ml/d. These flows are significantly reduced by backwater effects of Goulburn flows which enter downstream. On at least two occasions this century during peak flood conditions the hydraulic gradient has been reversed and the Murray has flowed north through Barmah. Spills on the Victorian side into the Barmah Forest return to the main river upstream of Barmah so the forest in this case serves as a detention pondage. On the north side the spills pass to the Edward-Wakool system and eventually return to the River Murray at Wakool Junction. The flow paths are illustrated by the 1974 and 1975 charts (Figs. 1 & 5).

The distribution of major flood flows in this tract (Fig. 5) shows that a peak flow of 275,000 Ml/d at Yarrawonga resulted in a peak flow of only 31,900 Ml/d at Barmah. The remaining floodwaters escaped to the Edward-Wakool system. The additional contribution from the Lower Goulburn of some 104,000 Ml/d resulted in a peak flow of only 100,000 Ml/d at Echuca. Similarly during the 1974 flood (Fig. 1) the peak flows recorded at Barmah and Echuca were 30,000 Ml/d and 98,000 Ml/d respectively, even though the corresponding flood peaks at Tocumwal and in the Lower Goulburn were, respectively, 202,000 Ml/d and 214,000 Ml/d.

The behaviour of the flood flow paths can be attributed to the land forms established in this tract before and after faulting impeded the westerly flow of the River Murray. Harris (1939) suggested that 'changes were effected by a number of displacements' on the Cadell Fault. The old ancestrals of the Murray were disrupted and caused to flow along the Gulpa Creek at the toe of the fault escarpment to Deniliquin (Pels 1966). Later the younger ancestrals followed the old for a short distance beyond Tocumwal, left them and formed the Bullatale Creek flood plain. During these river changes Lake Kanyapella and the Moira lakes were formed.

The present river broke away from the ancestral flood plains downstream from Tocumwal and formed a new channel beside the old ancestral Murray to Picnic Point. It has breached a lunette, and turned south across the Moira Lake floor to Barmah. The river eroded through the Riverine Plain at Barmah, continued south and broke through the Barma sand hills to flow west across the former Lake Kanyapella floor to the Goulburn River. These landforms and the history of formation were described by Bowler and Harford (1966) and later in more detail by Bowler (1970).

The meander belt is narrow, 150 m, and the meander wave lengths are less than 1,000 m. The modern channel is less than 75 m wide and is cut to a depth greater than 15 m. The bed of the channel is composed predominantly of fine sand, and its banks of clay.

THE ANCESTRAL GOULBURN TRACT

The River Murray enters the ancestral Goulburn flood plain on the floor of the former Lake Kanyapella, upstream of Echuca. From this location to the Wakool junction the river breaks out of the ancestral Goulburn course at Torrumbarry and returns to it at Swan Hill.

Flood flow patterns continue to be influenced by the lake floor systems in the upper portion of this tract. The effect at Echuca of coincident flood flows in the Campaspe River is of major importance. A coincident Campaspe flood produces a backwater effect in the Murray at the township, and it is this backwater effect superimposed on a flood in the Murray-Goulburn system which causes a significant rise in flood levels at Echuca. In 1870 and in 1916 the increase in flood level as a result of the impact of the Campaspe was 1 m and 1.5 m respectively. Eventually a level is reached at which water escapes to New South Wales over a long stretch of bank downstream of Echuca and this probably occurred during the highest recorded flood in 1870.

From Echuca to Wakool Junction the flood plain section is still very limited (Fig. 4d) and further escapes to the Edward-Wakool system occur at many places between Torrumbarry Weir and Swan Hill. On the Victorian side, although major overflows near Torrumbarry have been controlled by levees, substantial volumes of water flow into the Gunbower-Koondrook forest (including along an ancestral course passing towards Kerang). From Torrumbarry to Swan Hill levees have been constructed along both sides of the river. However they are still at levels which result in their being overtopped in major floods. This allows water to flow up and along its ancestral flood plains in some sections, and onto the Riverine Plain in others.